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# Below-ground biomass of 10-, 20-, and 32-year-old *Populus tremuloides* in Wisconsin

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With 2 figures

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## 1. Introduction

Increased fiber utilization and shorter rotations have been proposed for managing aspen in the Great Lakes region (Anonymous 1980). Aspen is regenerated in this region by root suckering following clearcutting (Perala 1979). Intensive forestry practices may impinge on the aspen root system, influencing nutrient distribution and future productivity of these stands. Although the physiological and morphological responses of aspen root systems after harvest have been examined (Santantonio *et al.* 1977, Schier & Campbell 1978, Zahner & DeByle 1965), the distribution and amount of root biomass for successionary aspen stands remain largely undefined. Accurate estimates of root biomass are needed to construct ecosystem nutrient budgets and provide estimates of potential biomass removal.

Large and small aspen roots have different distribution patterns (Brown 1935, Schier 1981). Roots less than 3 mm in diameter (small roots) originate from long, relatively untapered scaffold roots. These small roots tend to fan out through the soil in response to soil moisture and nutrients. This habit leads to a relatively small-scale distribution pattern for this size class, but their below-ground biomass levels may fluctuate widely during the year (Brown 1935, Harris *et al.* 1977). Roots greater than 3 mm in diameter (large roots) are less branched, extend laterally near the soil surface, and are more variable in distribution than small roots.

The large root biomass of forest trees can be subdivided into 2 distinct populations (Ford & Deans 1977). One population resides directly under the stem while a second population lies between the stems. The former population can be measured by extracting stumps and weighing the attached root mass. If sufficient stumps are removed, regression equations can be used to predict stump and root mass from stem diameter (Young *et al.* 1980). Estimation of the second population of large roots, lying between stems, is more difficult. The distribution pattern of these roots makes statistically accurate estimates of their biomass intractable unless large volumes of soil are analyzed (Reynolds 1970). Both populations need to be measured for an accurate estimate of below-ground biomass.

The main objective of this study was to determine the amount of root biomass within the aspen ecosystem for an age sequence of successionary stands growing on a single soil series. Secondly, we refined a method for assessing root biomass and detailed the errors associated with the sampling system.

## 2. Experimental site

Three stands of even-aged, healthy, fully stocked (>90 % crown closure) trembling aspen were located in northern Wisconsin (45° 45′ N, 89° 45′ W). Three age classes were represented during the 1984 growing season: 10-, 20-, and 32-year-old aspen. Understory vegetation was dominated by *Corylus cornuta* (Marsh) and *Pteridium aquilinum* (L.) Kuhn. All stands were essentially pure aspen situated on a Vilas loamy sand (sandy, mixed, frigid, Entic Haplorthod). The Vilas soil is derived

from glacial outwash of late Wisconsin age (ca. 14,000 years BP) on level to gently sloping relief. The Vilas series has a weak fragipan at a depth of 60—70 cm. This layer does not restrict rooting but may perch water (Hole 1976).

The study area has a cool continental climate with mean monthly air temperature ranging from a low of —11 °C in January to a high of 19 °C in July. Precipitation falls primarily during the growing season and averages 800 mm year$^{-1}$. Site index is 24 m at base age 50 according to the curves of Graham *et al.* (1963).

## 3. Materials and methods

### 3.0. General

Differences in distribution patterns of small- and large-roots suggested the need for separate sampling strategies for these populations. Accordingly, the following account of methodology is partitioned into 2 main sections to reflect these differences. The large root section is further subdivided into 2 subsections. A random sampling scheme was used for the fine root populations, while systematic random approaches were adopted for the 2 subdivisions of large root biomass.

### 3.1. Plot layout

Above- and below-ground biomass were measured on a single 20 m × 12 m plot located randomly within each of the 3 stands. Stems were tallied for DBH, crown class, and species. All stems within each 240 m² area were harvested during the 1984 growing season. Above-ground aspen biomass was estimated using procedures of Pastor & Bockheim (1981), with modifications by Ruark (1985b). Above-ground biomass of understory vegetation was measured directly by harvesting 8 × 1 m² subplots per plot.

### 3.2. Small roots

Small roots were collected from each plot at four times during the 1983 growing season: 1 May, 12 June, 11 August, and 12 October. Eight sample points were randomly located within each plot during a sampling episode. Samples were not taken within 30 cm of a previous sample point. A slide-hammer driven, coring device with an inside diameter of 5.5 cm was constructed for sampling small roots (Ruark 1985a). Samples were partitioned into 3 successive 10 cm depth increments. The 8 sample points on a plot were composited for each depth increment. However, on the 19-year-old site all sample points were maintained separately to estimate within-plot sample variation.

A root washing table was designed to separate roots from soil. The table incorporated the principle of flotation onto nested screens of diminishing sizes (Böhm 1979). Dead roots and organic debris were identified by their friability and loss of integrity and discarded (Böhm 1979). Live aspen roots were sorted from live understory roots under a 5-power lighted lens. For the 0—10 cm depth samples, it was necessary to subsample the material that remained after all obvious roots were removed. A 10% sample by mass of the residual was sorted under a 20-power dissecting microscope. Aspen small roots (ASPSM) were sorted into $< 0.5$ mm and 0.5—3 mm diameter classes. Understory small roots (USSM) were defined as 3 mm or less in diameter. Roots were dried to constant mass at 65 °C prior to weighing.

### 3.3. Large roots

#### *3.3.0. General*

Three trenches, one on each plot, were installed with a backhoe during June 1984. The trenches were 20 m long, 2 m wide, and 1.5 m deep. Sample design assumed that there are two distinct populations of large tree roots. The first population resides under a stem and within a small area encircling it. This surrounding area was termed the buffer zone. For field operation, 10- and 20-year-old stems were considered to have a 30-cm buffer zone, while 32-year-old stems were assigned a 50-cm buffer. Thus, a 32-year-old stem with a DBH of 25 cm was considered to have population 1 lying under a circular area 1.25 m in diameter. A 50-cm buffer could not be used for the 10- and 20-year-old stands as the dense stocking levels would have precluded the location of between-buffer monoliths. Alternatively, a 30-cm buffer on 32-year-old stems would not be sufficient to avoid cutting large diameter main roots emanating from the stump. In terms of stand area coverage, the extent of population 1 was determined by increasing all stem diameters by twice their buffer area and summing the areas of these circles. Population 2 was situated in the remaining area not allocated to population 1.

#### *3.3.1. Population 1 sampling*

Fifteen stumps were removed from the 10-year-old stand, 15 from the 20-year-old, and 8 from the 32-year-old stand. The DBH of trees from which stumps were collected ranged from 4—20 cm. A circular buffer zone was delineated on the ground around each stump. Roots crossing this zone were severed and stumps were extracted by alternately shoveling, chopping, and hand-winching.

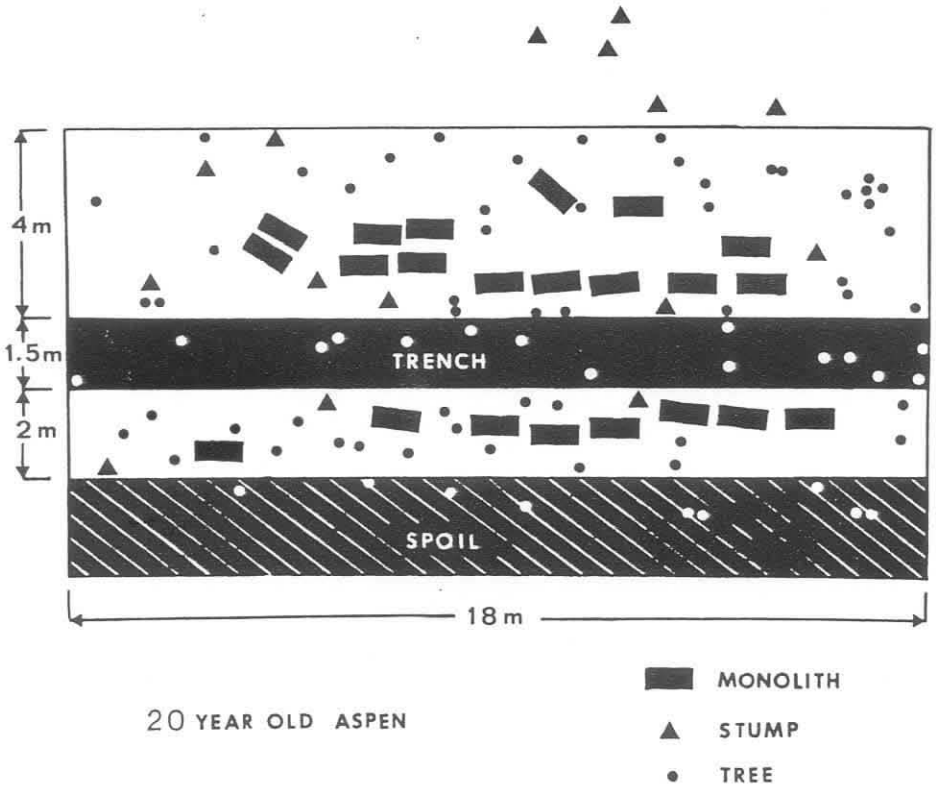


Fig. 1. Diagram of trench excavation in the 20-year-old stand.

Soil was removed from the root systems of extracted stumps. All roots greater than 3 mm in diameter and located within the buffer zone to a depth of 60 cm were separated from the soil by dry sieving. The roots under a given stump-buffer region were composited over the 0—60 cm depth. Roots attached to the stump were trimmed off until only roots exceeding a 30 mm diameter remained. Stumps were cut flush with the ground just above the root collar. Henceforth, this remaining mass will be referred to as a stump. The roots for a given stump-buffer zone were sorted into 3 categories: (**1**) aspen large roots (ASPLG); (**2**) aspen stump; (**3**) understory large roots (USLG). Large roots of aspen and understory vegetation each were divided into 3—10 and 10—30 mm diameter classes, rendering 5 size class (including aspen stumps).

### *3.3.2. Population 2 sampling*

Methodology for estimating large roots situated between buffer zones was identical for the 3 sites. Twenty-two monoliths of soil measuring 1 m × 0.5 m and 0.6 m deep were prepared along each trench (Fig. 1). The monoliths were located so as to avoid inclusion of any stem buffer region and to preclude overlap with population 1. The soil was removed from each monolith in depth increments: 0—10, 10—20, 20—30, 30—40, and 40—60 cm. Soil was passed through a field sieve and all roots >3 mm in diameter were retained. Roots were washed and sorted into aspen and understory categories, and dried at 65 °C.

## 3.4. Statistical methods

Paired t-tests were conducted on the small root biomass data to detect differences in the small root pool during the growing season and with stand age. One-way analysis of variance (OAV) was used to assess differences in small root biomass with mineral soil depth. Prior to analyzing the ASPLG biomass data for population 1, the data for 10- and 20-year-old stands were converted from a 30- to a 50-cm buffer basis. An appropriate proportion of the mean ASPLG biomass for the 22 soil monoliths of population 2 on each plot was added to each stump buffer. The ASPLG biomass and aspen stump masses within a standardized 50-cm buffer zone were then regressed against stem DBH. The power function ($Y = aX^b$) was directly fitted to untransformed data by the NREG77 non-linear curve fitting package (Lin & Tutsch 1982). The biomass of USLG roots for population 2 was analyzed by OAV for the 22 soil monoliths on each plot.

# 4. Results

## 4.1. Small root biomass

Biomass of aspen small roots (ASPSM) ranged narrowly between 1.5 and 2.9 Mg $ha^{-1}$, regardless of stand age or time of sampling (Table 1). The 8 individual samples which comprise the mean values for the 20-year-old stand totals produced coefficients of variation

Table 1. Variation in small-root (≤ 3 mm dia.) biomass of aspen by month, depth, and stand age

| Age (yrs) | Depth[a] (cm) | May Mg ha$^{-1}$ | June | August | October |
|---|---|---|---|---|---|
| 10 | 0—10 | 1.526 | 1.178 | 0.853 | 1.523 |
| | 10—20 | 0.782 | 0.572 | 0.681 | 0.795 |
| | 20—30 | 0.588 | 0.270 | 0.285 | 0.099 |
| | **Total** | **2.896** (0.42)[b] | **2.020** (0.28) | **1.819** (0.23) | **2.417** (0.55) |
| 20 | 0—10 | 0.886 (0.17) | 0.817 (0.17) | 0.926 (0.18) | 1.294 (0.25) |
| | 10—20 | 0.513 (0.15) | 0.507 (0.11) | 0.535 (0.10) | 0.632 (0.30) |
| | 20—30 | 0.113 (0.03) | 0.282 (0.10) | 0.335 (0.17) | 0.226 (0.11) |
| | **Total** | **1.512** (0.22) | **1.606** (0.22) | **1.796** (0.23) | **2.152** (0.49) |
| 32 | 0—10 | 1.267 | 0.984 | 0.804 | 1.053 |
| | 10—20 | 1.063 | 0.804 | 0.514 | 0.557 |
| | 20—30 | 0.595 | 0.172 | 0.305 | 0.362 |
| | **Total** | **2.925** (0.43) | **1.960** (0.27) | **1.623** (0.21) | **1.972** (0.45) |

[a]) Biomass decreased significantly ($P < 0.05$) with depth among soil layers when averaged for all sampling periods.

[b]) Numbers in parentheses are the standard errors of the means (SEM); n = 8. The coefficient of variation from the corresponding monthly sample from the 20-years-old stand was imposed on the other two stands for calculation of monthly SEM.

Table 2. Variation in small-root (≤3 mm dia.) biomass understory vegetation by month, depth, and stand age

| Age (yrs) | Depth[a] (cm) | June Mg ha$^{-1}$ | August | October |
|---|---|---|---|---|
| 10 | 0—10 | 3.595 | 4.504 | 5.712 |
| | 10—20 | 1.908 | 3.201 | 1.755 |
| | 20—30 | 0.907 | 1.055 | 0.894 |
| | **Total** | **6.410** (0.99)[b] | **8.760** (0.69) | **8.361** (0.71) |
| 20 | 0—10 | 2.095 (0.57) | 2.831 (0.48) | 4.139 (0.40) |
| | 10—20 | 1.648 (0.41) | 1.518 (0.27) | 1.535 (0.36) |
| | 20—30 | 1.048 (0.22) | 0.737 (0.13) | 1.370 (0.23) |
| | **Total** | **4.791** (0.99)[b] | **5.086** (0.69) | **7.044** (0.60) |
| 32 | 0—10 | 3.351 | 3.984 | 5.570 |
| | 10—20 | 1.625 | 1.603 | 2.078 |
| | 20—30 | 0.920 | 0.979 | 0.828 |
| | **Total** | **5.896** (0.91) | **6.566** (0.52) | **8.476** (0.72) |

[a]) Biomass decreased signficantly ($P < 0.05$) with depth among soil layers when averaged for all sampling periods.

[b]) Numbers in parentheses are the standard errors of the means (SEM); n = 8. The coefficient of variation from the corresponding monthly sample from the 20-year-old stand was imposed on the other two stands for calculation of monthly SEM.

Table 3. Average stand small-root biomass

| Age (yrs) | Aspen | | | Understory | Understory |
|---|---|---|---|---|---|
| | <0.5 mm Mg ha$^{-1}$ | 0.5—3 mm | <3 mm | <3 mm | % in fine root pool |
| 10 | 0.45 (0.04)[a] | 1.84 (0.19) | 2.29 (0.27) | 7.84 (0.89)[b] | 77.4 |
| 20 | 0.45 (0.06) | 1.32 (0.09) | 1.77 (0.16) | 5.64 (0.87) | 76.1 |
| 32 | 0.50 (0.08) | 1.62 (0.32) | 2.12 (0.32) | 6.97 (0.95) | 76.7 |

[a]) Mean of 4 monthly samples, each sample constructed from 8 composited points. Samples collected in May, June, August, and October of 1983. Standard errors of the monthly means are given in parentheses.

[b]) Means for non-aspen samples for only 3 months, June, August, and October of 1983.

Table 4. Equation for Aspen large-root biomass — Population 1 and population 2 —

| Component | Form | A | B | X | $r^2$ | See |
|---|---|---|---|---|---|---|
| Within buffer | | | | | | |
| 3—10 mm | P | 0.0491 | 1.054 | DBH | 0.916 | 0.07 |
| 10—30 mm | P | 0.0952 | 0.967 | DBH | 0.541 | 0.29 |
| 3—30 mm | P | 0.1418 | 1.006 | DBH | 0.788 | 0.29 |
| Stump | P | 0.0129 | 2.371 | DBH | 0.974 | 0.53 |
| Stump plus 3—30 mm | P | 0.0421 | 2.028 | DBH | 0.964 | 0.74 |
| Between buffer 3—30 mm | L | 0.976 | —0.019 | AGE | 0.475 | 0.17 |

a) P) ower: $Y = AX^B \ldots Y = (kg\ m_x)/BUFFER$; X = cm
L) inear: $Y = A + BX \ldots Y = (kg\ m_x)/m^2$; X = years.

b) SEE = standard error of the estimate.

c) 50 cm buffer used (WITHIN: n = 38; BETWEEN: n = 66).

Note: $m_x$ (xero-mass) ≙ o. d. wt. (oven dried weight).

Table 5. Monolith-aspen large-root biomass ($g\ m^{-2}$)
Population 2

| Depth (cm) | Aspen roots (3—10 mm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Age (years) 10 | | | 20 | | | 32 | | |
| | a | b | c d | | | | | | |
| 0—10 | A | 114.8 | (13.6) W | A | 80.6 | (9.1) W | A | 76.2 | (8.4) W |
| 10—20 | A | 51.8 | (6.7) X | A | 69.8 | (8.1) W | A | 61.6 | (8.4) WX |
| 20—30 | A | 21.8 | (3.2) Y | B | 63.6 | (6.1) WX | B | 48.4 | (8.0) XY |
| 30—40 | A | 10.4 | (2.0) Y | B | 40.8 | (6.4) X | AB | 24.8 | (4.2) YZ |
| 40—60 | A | 11.0 | (2.5) Y | A | 11.4 | (2.0) Y | A | 18.0 | (4.7) Z |
| **Total** | A | **209.8** | (17.1) | A | **266.4** | (15.3) | A | **229.0** | (19.3) |
| | Aspen roots (10—30 mm) | | | | | | | | |
| Depth (cm) | Age (years) 10 | | | 20 | | | 32 | | |
| 0—10 | A | 406.4 | (41.1) W | B | 133.4 | (21.2) W | B | 69.0 | (39.6) W |
| 10—20 | A | 97.6 | (20.3) X | AB | 90.8 | (16.4) WX | B | 27.4 | (7.1) W |
| 20—30 | A | 57.4 | (15.3) XY | A | 69.0 | (17.4) XY | A | 51.2 | (20.7) W |
| 30—40 | A | 18.4 | (10.5) YX | A | 28.2 | (10.9) YZ | A | 18.4 | (7.4) W |
| 40—60 | A | 5.2 | (4.3) Y | A | 0.6 | (0.4) Z | A | 19.0 | (11.1) W |
| **Total** | A | **585.0** | (51.6) | B | **322.0** | (29.0) | B | **185.0** | (57.6) |
| | Aspen roots (3—30 mm) | | | | | | | | |
| Depth (cm) | Age (years) 10 | | | 20 | | | 32 | | |
| 0—10 | A | 521.2 | (43.5) W | B | 214.0 | (23.5) W | B | 145.0 | (41.2) W |
| 10—20 | A | 149.5 | (22.8) X | A | 160.6 | (21.3) WX | A | 89.1 | (13.6) WX |
| 20—30 | A | 79.3 | (16.8) XY | A | 132.6 | (18.3) XY | A | 99.8 | (24.1) WX |
| 30—40 | A | 28.9 | (12.1) Y | A | 69.2 | (13.5) YZ | A | 43.4 | (10.3) X |
| 40—60 | A | 16.3 | (5.1) Y | A | 12.0 | (2.2) Z | A | 37.0 | (13.1) X |
| **Total** | A | **794.8** | (54.2) | B | **588.4** | (38.4) | B | **414.0** | (63.1) |

a) A and B denote age differences ($p < 0.05$) at a given depth.

b) mean root biomass, number of samples equals 22 for each mean.

c) standard error of mean given in parentheses.

d) W, X, Y, and Z denote depth differences ($p < 0.05$) at a given age.

Table 6. Monolith-understory large-root biomass (g $m^{-2}$)
Population 2

| Depth (cm) | Understory roots (3—10 mm) Age (years) 10 | | | | 20 | | | 32 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | c | d | | | | | | |
| 0—10 | AB | 180.4 | (20.5) | W | A | 110.8 | (17.2) W | B | 219.6 | (23.9) W |
| 10—20 | AB | 79.4 | (7.5) | X | A | 57.6 | (6.8) X | B | 101.8 | (13.0) X |
| 20—30 | AB | 15.8 | (3.3) | Y | A | 8.8 | (2.0) Y | B | 28.0 | (3.8) Y |
| 30—40 | A | 7.2 | (3.2) | Y | A | 2.2 | (0.7) Y | A | 14.7 | (5.2) Y |
| 40—60 | A | 2.1 | (1.0) | Y | A | 1.2 | (0.3) Y | B | 14.3 | (4.9) Y |
| **Total** | A | 284.9 | (24.8) | | B | 180.6 | (20.2) | A | 378.4 | (26.3) |
| | Understory roots (10—30 mm) | | | | | | | | | |
| Depth (cm) | Age (years) 10 | | | | 20 | | | 32 | | |
| 0—10 | A | 63.2 | (20.2) | W | A | 61.6 | (29.4) W | A | 161.0 | (36.1) W |
| 10—20 | A | 5.4 | (2.7) | X | A | 20.6 | (11.5) W | A | 59.6 | (23.1) X |
| 20—30 | A | 5.8 | (3.2) | X | A | 0.0 | X | A | 35.2 | (15.7) X |
| 30—40 | A | 2.5 | (1.5) | X | A | 0.0 | X | A | 0.9 | (0.6) X |
| 40—60 | A | 1.0 | (0.7) | X | A | 0.0 | X | A | 1.3 | (1.3) X |
| **Total** | A | 77.9 | (22.2) | | A | 82.2 | (37.1) | B | 256.0 | (55.1) |
| | Understory roots (3—30 mm) | | | | | | | | | |
| Depth (cm) | Age (years) 10 | | | | 20 | | | 32 | | |
| 0—10 | AB | 244.0 | (39.0) | W | A | 172.4 | (44.5) W | B | 380.0 | (55.9) W |
| 10—20 | A | 84.8 | (7.8) | X | A | 78.2 | (14.6) X | B | 161.4 | (26.8) X |
| 20—30 | A | 21.6 | (4.7) | XY | A | 8.8 | (2.0) Y | B | 63.2 | (17.1) XY |
| 30—40 | A | 9.7 | (4.1) | Y | A | 2.2 | (0.7) Y | A | 15.6 | (5.2) Y |
| 40—60 | A | 3.2 | (1.3) | Y | A | 1.2 | (0.3) Y | B | 15.6 | (5.3) Y |
| **Total** | A | 362.8 | (44.3) | | A | 262.8 | (53.5) | B | 634.4 | (73.3) |

a) A and B denote age differences ($p < 0.05$) at a given depth.
b) mean root biomass, number of samples equals 22 for each mean.
c) standard error of mean given in parentheses.
d) W, X, Y, and Z denote depth differences ($p < 0.05$) at a given age.

(COV) around 14% for the May, June, and August sampling periods, while the COV rose to 23% during October. No significant differences among sampling periods were detected for a given stand with paired t-tests. However, there were significant differences ($P < 0.05$) among the 3 depth components on all 3 plots, with a decrease in seasonally averaged root biomass occurring with increasing depth. No discernable trends were attributable to stand age.

Biomass of understory small roots (USSM) ranged from 4.8 to 8.8 Mg $ha^{-1}$ (Table 2)[1]. The COV for the 20-year-old stand totals varied from 8 to 15% during the growing season. Based on paired t-tests, USSM increased significantly ($P < 0.05$) in the upper 10 cm of mineral soil from June to October, but total USSM in the upper 30 cm of mineral soil did not increase significantly over the growing season. However, USSM biomass decreased significantly ($P < 0.05$) with soil depth on all 3 plots. The biomass of USSM was not related to stand age.

Since the biomass of small roots was not significantly correlated with sampling period, the ASPSM and USSM for a given stand were averaged over the growing season (Table 3).

[1]) 1 Mg = $1 \cdot 10^6$ g ≙ 1 t [Mg = Mega-Gramme].

The 3 stands support similar aspen fine root (<0.5 mm) biomass pools of approximately 0.5 Mg $ha^{-1}$. The average total biomass of ASPSM ranged from 1.8 to 2.3 Mg $ha^{-1}$ for the 3 stands. The size of the USSM pool is roughly 3 times greater than that of the ASPSM pool, ranging from 5.6 to 7.8 Mg $ha^{-1}$. The < 0.5 mm component was not determined for understory species. 84% of the ASPSM biomass was in the upper 20 cm of mineral soil, while 86% of the USSM biomass occupied this same zone.

### 4.2. Large root biomass

The regression for the ASPLG 3—10 mm diameter class residing within the stump buffer region had a coefficient of determination ($r^2$) of 0.916 (Table 4). The estimate of parameter B in this regression is close to unity, indicating an essentially linear increase of this component with increasing DBH. Between buffers the distribution of ASPLG biomass in the 3—10 mm class did not differ significantly among stands, except at the 20—30 cm depth, where fewer roots were present in the 10-year-old stand (Table 5). The total biomass of 3—10 mm ASPLG between stems was similar for all ages.

The difficulty associated with predicting the biomass of large roots within the buffer zone is evidenced by the low $r^2$ (0.54) for the regression of large (10—30 mm) ASPLG roots on stem DBH (Table 4). Table 5 shows that the biomass of the 10—30 mm ASPLG size class between stems was significantly larger in the upper 10 cm of the 10-year-old stand than in the older stands. This resulted in a greater total biomass between buffers for this ASPLG size class on the 10-year-old plot.

Large aspen root size classes (3—10 and 10—30 mm) were combined into a 3—30 mm class. The predictability of this ASPLG size class from stem DBH was fair ($r^2 = 0.79$) (Table 4). Between buffers the only statistically different result for this size class among stands was the greater ASPLG biomass in the upper 10 cm of the 10-year-old stand, resulting in greater total ASPLG biomass between stems in the youngest stand (Table 5). The total mean ASPLG biomass for population 2 declined steadily with stand age, producing values of 795, 588, and 414 g $m^{-2}$ for the 10-, 20-, and 32-year-old plots, in turn. The respective COV were 7, 7, and 15%, respectively, for these 3 age groups. The proportion of stand ASPLG biomass at a given soil depth varied with stand age. The upper 20 cm of mineral soil contained 84, 63, and 56% of the total ASPLG biomass on the 10-, 20-, and 32-year-old plots, respectively.

It was not possible to predict the biomass of the understory large roots (USLG) within the buffer region by regression techniques. Values ranged from 249 to 525 g $m^{-2}$ of buffer. The analysis of USLG biomass lying between buffers was conducted in the same manner as for the ASPLG data. Table 6 illustrates a lower biomass of USLG in the 3—10 mm diameter class for the 20-year-old stand. Root distribution by depth followed the pattern: 0—10 $\gg$ 10—20 $\gg$ 20—30, 30—40, 40—60 cm for all ages. Total USLG biomass in the 10—30 mm diameter class was greatest in the 32-year-old plot. Root distribution trends were: 0—10 > 10—20, 20—30, 30—40, 40—60 cm for all ages.

Large understory root size classes were combined to form one 3—30 mm class. The total 3—30 mm USLG mass in the upper 60 cm was greater in the 32-year-old stand than the other stands. The COV for the total USLG biomass between buffers ranged from 12 to 20% on the 3 stands. The proportion of the total USLG biomass residing in the upper 10 cm of soil averaged 64% for all ages. Only 4—15% of the USLG biomass was located below the 20-cm depth.

### 4.3. Stump biomass

The biomass of aspen stump material was readily predicted from stem DBH and showed an exponential increase with increases in diameter (Table 4). The total biomass of stump plus ASPLG within a buffer was predicted with similar accuracy but exhibited a larger standard error of the estimate than the stump equation.

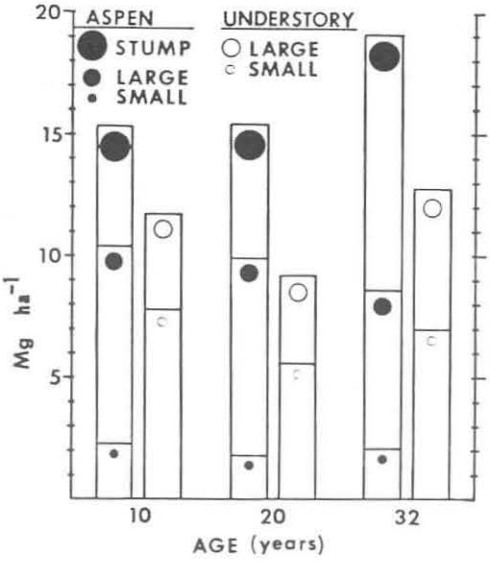


Fig. 2. Stand level root biomass for aspen and understory species.

### 4.4. Stand root and shoot totals

Above-ground aspen biomass was estimated at 38.1, 49.4, and 99.8 Mg ha$^{-1}$ for the 10-, 20-, and 32-year-old stands, respectively. Corresponding estimates of above-ground understory biomass were 2.2, 2.8, and 5.2 Mg ha$^{-1}$, in turn (Ruark 1985b).

The aspen root equations from Table 4 and the aspen and understory values from Tables 5 and 6 were used to estimate the total root biomass for each of the study plots. Operationally, the buffer region occupied 28, 13, and 19% of the land area in the 10-, 20-, and 32-year-old stand, respectively. This is based on the use of a 30-cm buffer in the 10- and 20-year-old stands. A 50-cm buffer was used in the 32-year-old stand. Since all buffers were adjusted to 50 cm prior to statistical analysis, the regression equations actually estimate ASPLG biomass of buffer regions that accounted for 74, 34, and 19% of the land base in the 10-, 20-, and 32-year-old stands, respectively. The remaining land area was estimated with the monolith data.

The total aspen root biomass in a stand rose slightly with increasing stand age from a low of 15.3 Mg ha$^{-1}$ to a high of 19.1 Mg ha$^{-1}$ (Fig. 2). This increase was attributable primarily to an increase in stump mass, which ranged from 3.9 Mg ha$^{-1}$ in the youngest stand to 10.5 Mg ha$^{-1}$ by age 32. The ASPSM remained constant over time, while ASPLG decreased slightly from age 10 to 32 years. The aspen root/shoot fell steadily from 0.40 at 10 years, to 0.31 at age 20, and 0.19 at 32 years.

The root/shoot of understory species averaged 12 times higher than that of aspen, decreasing from 5.3, to 3.2, to 2.5 from 10 to 32 years of age. The decrease in this ratio was the result of an increased above-ground mass, while total understory root biomass remained relatively constant with age. The biomass of USSM ranged from 5.6 to 7.8 Mg ha$^{-1}$, and was not correlated with stand age. Total roots of aspen and understory ranged from 24 to 32 Mg ha$^{-1}$ and were unrelated to age. Understory roots comprised from 37 to 45% of the total root biomass.

## 5. Discussion

### 5.1. Total small roots

The large amount of USSM biomass near the soil surface indicates an important competitive role within the aspen ecosystem for understory plants. These plants are favorably positioned to compete with aspen for soil nutrients and moisture. During the summer months, partial moisture recharge of the upper soil profile by moderate rains may primarily benefit understory species due to their higher root surface area relative to aspen. A reduction in the understory biomass component may result in increased aspen production. Conversely, the root density of the understory component may be beneficial on coarse-textured sites

for retention of nutrients within the ecosystem. The turnover and decomposition rates of understory roots likely differ from those of aspen roots. To date, these rates for understory roots are lacking, while similar information for aspen is minimal and conflicting. The use of different methods for calculation can produce estimates differing by 30 to 165% for annual fine-root turnover of trees when using the same data base (SANTANTONIO 1980, MCCLAUGHERTY *et al.* 1982).

Visual inspection of aspen stumps revealed a proliferation of ASPSM emerging directly from the stump. This rooting behavior has been attributed to favorable conditions produced by stemflow (FORD & DEANS 1977). A cursory evaluation indicated that the concentration of ASPSM biomass within the stump buffer did not differ appreciably from the mean concentration of ASPSM obtained via random soil cores. This information suggests that extrapolation of core-derived small root estimates to an area basis without subtraction of basal area may be problematic. However, since the distribution of ASPSM within the buffer is less random, the use of a systematic random scheme (whereby core samples are not taken within a given distance from a stem) appears reasonable for estimating ASPSM. This would likely reduce the large standard errors commonly associated with estimates of small root biomass from simple random sampling schemes.

Interpretation of the small root pool within aspen ecosystems awaits further research on the mechanisms and interactions of the various species involved. Since USSM can comprise as much as 76% of this pool, future studies need to focus on the role of these plants and their interaction with aspen. More specifically, the role of understory root systems in the nutrient cycling of base cations within the aspen ecosystem should be explored.

### 5.2. Large aspen roots

The biomass of ASPLG located between buffers (population 2) showed a steady decrease with stand age. Most of this decrease was due to a reduction in biomass of the 10—30 mm diameter class in the 10 cm soil zone. This is likely due to attrition of suppressed stems whose stumps and large roots degrade following natural thinning episodes. This was reflected in stocking values of 10,500, 3,800, and 1,900 stems per hectare in the 10-, 20-, and 32-year-old stands, respectively. This decreasing trend for ASPLG with increasing stand age suggests that ASPLG biomass in the 10-year-old stand was produced following clearcutting rather than representing residual biomass from the previous rotation.

The decrease with stand age in total ASPLG biomass between buffers was offset by the greater percentage of non-buffer area in older, less-stocked stands and by the increase in ASPLG biomass within the stump buffer with increasing stem size. As a result, the ASPLG stand total remained relatively constant with stand age. However, the distribution of this root component changed so that ASPLG tended to reside closer to stems with increasing stand age. Consequently, there was more than 3 times the ASPLG biomass adjacent to stems in the oldest stand in contrast to the youngest stand. Rooting density between stems decreased by approximately half as stands aged from 10 to 32 years.

### 5.3. Total aspen roots

The total aspen root biomass of a stand increased over time (Fig. 2). Most of this increase was due to an increase in aspen stump mass. This was likely an architectural necessity in response to increased stem biomass with age. The ASPSM and ASPLG components of the root system retained relatively constant biomasses from 10 to 32 years of age, but the distribution pattern for ASPLG changed. An average of 62, 57, and 80% of the total aspen root system resided within the 50-cm buffer in the 10-, 20-, and 32-year-old stands, respectively.

Aspen root to shoot ratios in this study were large when compared to estimates by YOUNG *et al.* (1980) and they decreased with increasing stand age. Total tree root biomass, when expressed as a percent of total tree biomass, was 29, 24, and 16% for the 10-, 20-, and 32-year-old stands, respectively. KEYES & GRIER (1981) found that species growing on

low fertility sites tended to produce larger root structures than when the same species grew on a fertile site. The site index of 24 m at 50 years determined for these sites from the curves of GRAHAM *et al.* (1963) indicates that our sites were of intermediate quality.

### 5.4. Total understory roots

The biomass estimates of USLG displayed large standard errors of the mean. Consequently, the estimates of total USLG biomass for populations 1 and 2 on each site were not statistically different. The amount of USLG and ASPLG within a given monolith were not significantly correlated.

There was more total aspen root biomass relative to understory root biomass on all plots. However, if only the sum of the small and large roots is considered (excluding stumps), the total understory root biomass exceeded that of aspen on the 10- and 32-year-old plots. The root/shoot values for these plants greatly exceeded those of aspen. *Pteridium aquilinum* accounted for most of the understory below-ground weight, followed by *Corylus cornuta*. The decrease in the root/shoot of the understory with increasing stand age is primarily the result of an increase in the shoot component of *Corylus cornuta*.

## 6. Conclusions

Aspen root biomass increased with stand age, largely as a result of an increment in stump mass The small and large root components of this system maintained relatively constant biomass pools from 10 to 32 years of age, but the distribution of large roots became more concentrated near the stem with age. Aspen root to shoot ratios declined from 0.40 to 0.19 between 10 and 32 years.

Understory root biomass was similar between and adjacent to stems. Understory species comprised approximately 76% of the total small root pool. The magnitude of this root mass indicates a major role in the nutrient and moisture regimes within the aspen ecosystem for these plants.

## 7. Acknowledgments

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**Synopsis:** *Original scientific paper*
RUARK, G. A., & J. G. BOCKHEIM, 1987. Below-ground biomass of 10-, 20-, and 32-year-old *Populus tremuloides* in Wisconsin. Pedobiologia **30**, 207—217.

Biomass of small (< 3 mm) and large (3—30 mm) aspen roots, aspen stumps, and roots of understory vegetation was measured in 3 age classes of trembling aspen. Regression equations were constructed for prediction of biomass of stumps and large roots lying under stems from bole diameter at 1.35 m. Root biomass located between tree stems was determined by sieving soil monoliths. Aspen root biomass (including stumps) increased with age from 15.3 to 19.1 Mg $ha^{-1}$ and comprised from 29 to 16 % of the total stand tree biomass, respectively. Most of the increase in root biomass over time was due to an increase in stump material. Understory roots composed 76 % of the small-root biomass in all three stands. There was no significant seasonal variation in small aspen and understory root biomasses. However, both small and large aspen roots declined significantly with depth, particularly below 20 cm. Aspen root to shoot ratios (R/S) were 0.40 and 0.19 for 10 and 32-year-old stands, respectively. The R/S of understory species averaged 12 times greater than that of aspen in 20-year-old stand. Understory roots play a major role in the nutrient and moisture regimes of aspen ecosystems in northern Wisconsin.
**Key words:** Below-ground biomass, roots, aspen, *Populus tremuloides*, nutrient, moisture regime.